SECTION XI

THE EXISTING LIMNOLOGICAL CONDITION OF LAKE HOPATCONG

A. INTRODUCTION

The limnological study of Lake Hopatcong quantifies its physical, chemical, and biological properties. These data have been used to characterize the existing condition of the lake as related to water quality and pertinent ecological interactions. They are also utilized in the identification of those problems which have or threaten to contribute to the deterioration of the lake. This section of the report is therefore of great importance. The data contained herein serves as the technical foundation upon which the future management and restoration of the lake will be based.

B. HISTORICAL WATER QUALITY

As New Jersey's largest inland water body, Lake Hopatcong has been the subject of numerous studies. The fishery, aquatic macrophytes, phytoplankton dynamics, and water quality of the lake have been investigated. As a result, a substantial data base exists for Lake Hopatcong.

A minor assessment of the lake's water quality was conducted by NJ Division of Fish and Game as a part of a fishery survey of the lake (NJ Dept. C.E.D., 1950). The lake was found to thermally stratify during the summer. From July through August the hypolimnion was devoid of oxygen. The anoxic zone reportedly extended from a depth of 10 meters to the lake bottom in the central main basin of the lake, and from a 5 meter depth in the deeper sections of Woodport Bay. The lake was observed to be slightly alkaline (7.3 pH) at the surface but slightly acidic (6.7 pH) at greater depths. In general, the lake was considered to be of acceptable environmental condition.

A more intensive study of the lake's water quality was conducted as part of the EPA National Eutrophication Survey (USEPA, 1976). The objective of the study was to investigate nutrient sources, loads, and impacts and summarize the trophic state of the lake. The results of that study concluded that Lake Hopatcong was receiving a nutrient load <u>below</u> that considered sufficient to stimulate or support nuisance algae blooms. The lake was reported to be of low to moderate primary production (Chlorophyll a concentrations of 5.5 mg m^{-3} to 27.7 mg m^{-3}), and low secchi disk transparency (0.6 m to 1.08 m). In the summer, oxygen became depleted at depths greater than 5 meters. Of the various nutrient sources, non-point tributary inputs (surface runoff) contributed the most to the annual total phosphorus budget (33.8%).

Sewage treatment plants, septic leakage, and direct precipitation contributed 26.7%, 24.8%, and 14.7% of the annual TP load, respectively (Appendix A).

In 1978 through 1980, a detailed investigation of the lake's macrophyte and phytoplankton communities was conducted (EAC, 1980). Analysis and discussion of these data will be covered in upcoming sections of this report. In summary, that study concluded that certain sections of the lake are plagued by nuisance densities of aquatic macrophytes. It advocated mechanical weed harvesting as a means of maintaining macrophyte standing crops at acceptable densities, and demonstrated, through an experimental harvesting program, the benefits accrued through such an operation. In addition, the study concluded that the phytoplankton community was dominated by diatoms and bluegreen algae. Chlorophyll concentrations, a measure of productivity, were greatest in Woodport Bay and River Styx, substantiating the highly productive nature of these two sections of the lake.

In 1974 a sampling program designed to monitor lake water quality was developed under the auspices of LHRPB. A number of physical-chemical parameters as well as bacteriological samples were examined at several locations throughout the lake. The majority of the samples were taken at the surface, although the deepest section of the lake, near Nolan's Point, was occasionally sampled. These data provide a basis for the examination of recent water quality trends.

Dissolved oxygen concentrations were observed to steadily decrease throughout the summer months even at the surface water stations. Although the dissolved oxygen concentration of the hypolimnion was not observed to become depleted, concentrations did approach anoxia, and reached levels unacceptable for the existence of most aquatic organisms.

Total phosphate, orthophosphate, nitrate, and ammonia were typically measured at concentrations indicative of an overly enriched system. However, the analytical methodology employed in these surveys was somewhat inconsistent. In addition, the measured concentrations were often near or at the analytical detection limit making these data somewhat suspect. Even in view of these potential shortcomings, the data do indicate that the lake's total phosphate concentration is sufficient enough to support nuisance algae blooms.

The data collected in these previous studies are indicative of conditions and characteristics normally associated with a eutrophic water body. Nutrient concentrations are high, a substantial volume of the lake becomes anoxic following thermal stratification, and the level of primary production is at times excessive. All are symptoms of accelerated eutrophication and are associated with water bodies of deteriorating environmental condition.

The objectives of our study include the assessment of the lake's trophic status, identification and quantification of nutrient sources, and analysis of the lake's ecological relationships. The historical data base provide a source of reference or comparison for the findings of our study. In addition, some of the data are used to supplement our study.

Table 31

PROPORTION OF LAKE VOLUME AT VARIOUS DEPTHS

Depth	Contour	Volume Between Successive Contour	Volume at or Above Each Contour
m	ft	m^3	m^3
0-1.52	0-5	1.406×10^7	1.406×10^7
1.52-3.05	5-10	1.052×10^7	2.46×10^7
3.05-4.57	10-15	7.30×10^6	3.19×10^7
4.57-6.09	15-20	6.30×10^6	3.82×10^7
6.09-7.61	20-25	5.60×10^6	4.38×10^7
7.61-9.13	25-30	4.71×10^6	4.85×10^7
9.13-10.65	30-35	3.66×10^6	5.22×10^7
10.65-12.17	35-40	2.75×10^6	5.50×10^7
12.17-13.69	40-45	1.86×10^6	5.69×10^7
13.69-15.21	45-50	5.00×10^5	5.74×10^7
15.21-16.73	50-55	1.57×10^5	$5.76 \times 10^{7*}$
TOTAL VOLUME		5.74×10^7	

*Error due to rounding figures.

2. Temperature

The lake is dimictic, that is, it undergoes complete mixing twice a year, once in the spring and once in the fall. The lake becomes thermally stratified in late June and remains so through August and into early September (Figure 6). The thermocline forms at a depth of approximately 9 m and fluctuates only slightly in depth from the surface throughout the period of stratification. The volume of the epilimnion is 48.5×10^6 m^3 while that of the hypolimnion is 8.9×10^6 m^3.

The temperature of the surface waters varies with ambient temperatures, ranging from 0^oC to 27^oC (Appendix C). The more elevated summer temperatures are recorded for the shallow embayments. The temperature of the deeper waters of the lake (>9 m) is more consistent ranging from 1.0^oC to 18^oC.

3. Dissolved Oxygen

Following summer stratification, the difference in density between the surface and bottom waters is great enough to minimize mixing of these two layers. This is important in relation to internal recycling of nutrients, productivity, and especially oxygen depletion. Dissolved oxygen concentration measurements taken concurrent with temperature, show that following stratification oxygen depletion commences in the deep non-mixed hypolimnion of the lake (Figures 7a, 7b, 7c, and 7d). In May, immediately following the establishment of the thermocline, there is 6.35×10^4 kg of oxygen in the hypolimnion. By the end of June, the oxygen content of the hypolimnion at depths greater than 12 meters has become completely exhausted (Figures 8a, 8b, 8c, and 8d). Bacterial

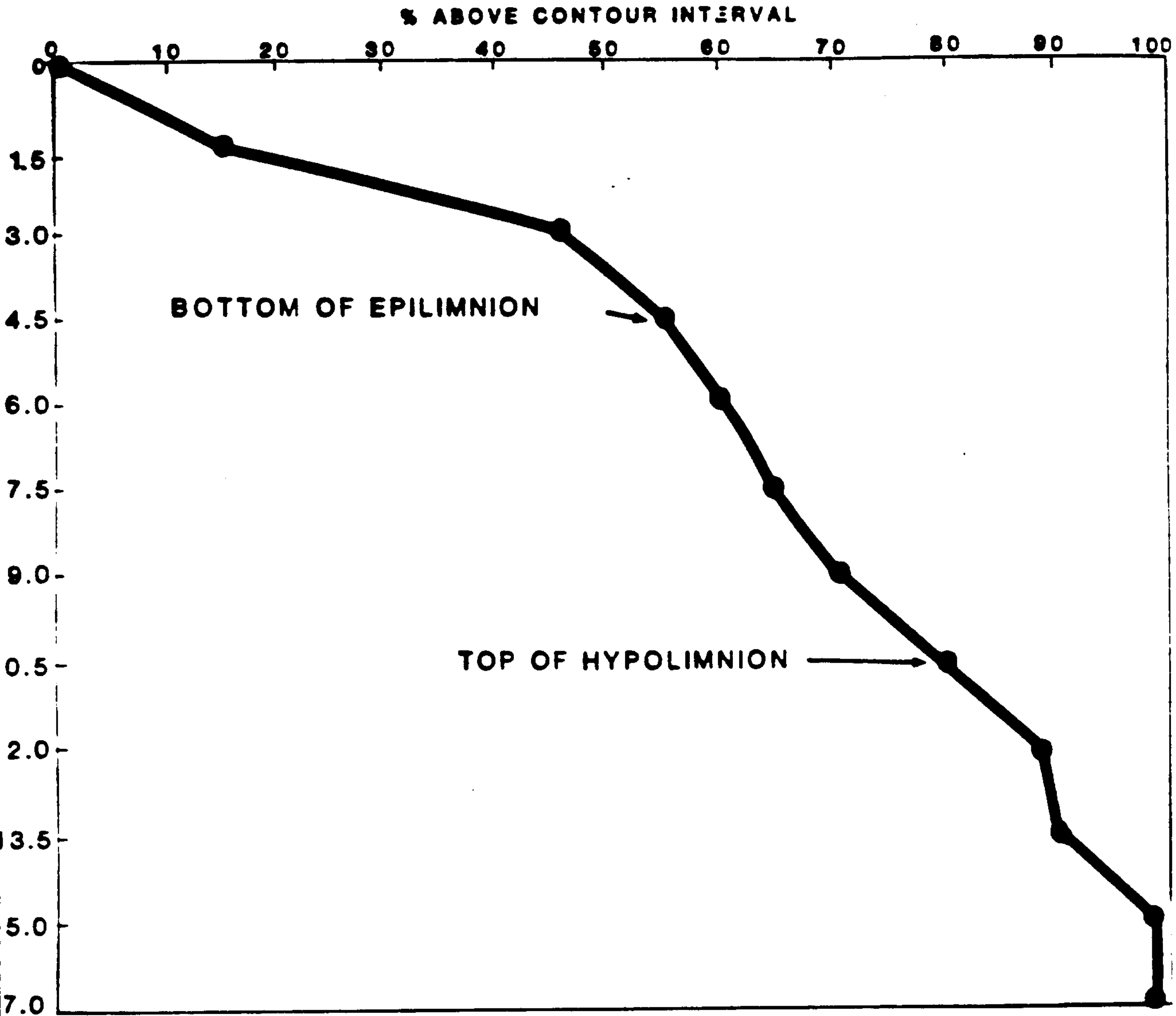


FIGURE 6
HYPSOGRAPHIC CURVE OF LAKE HOPATCONG

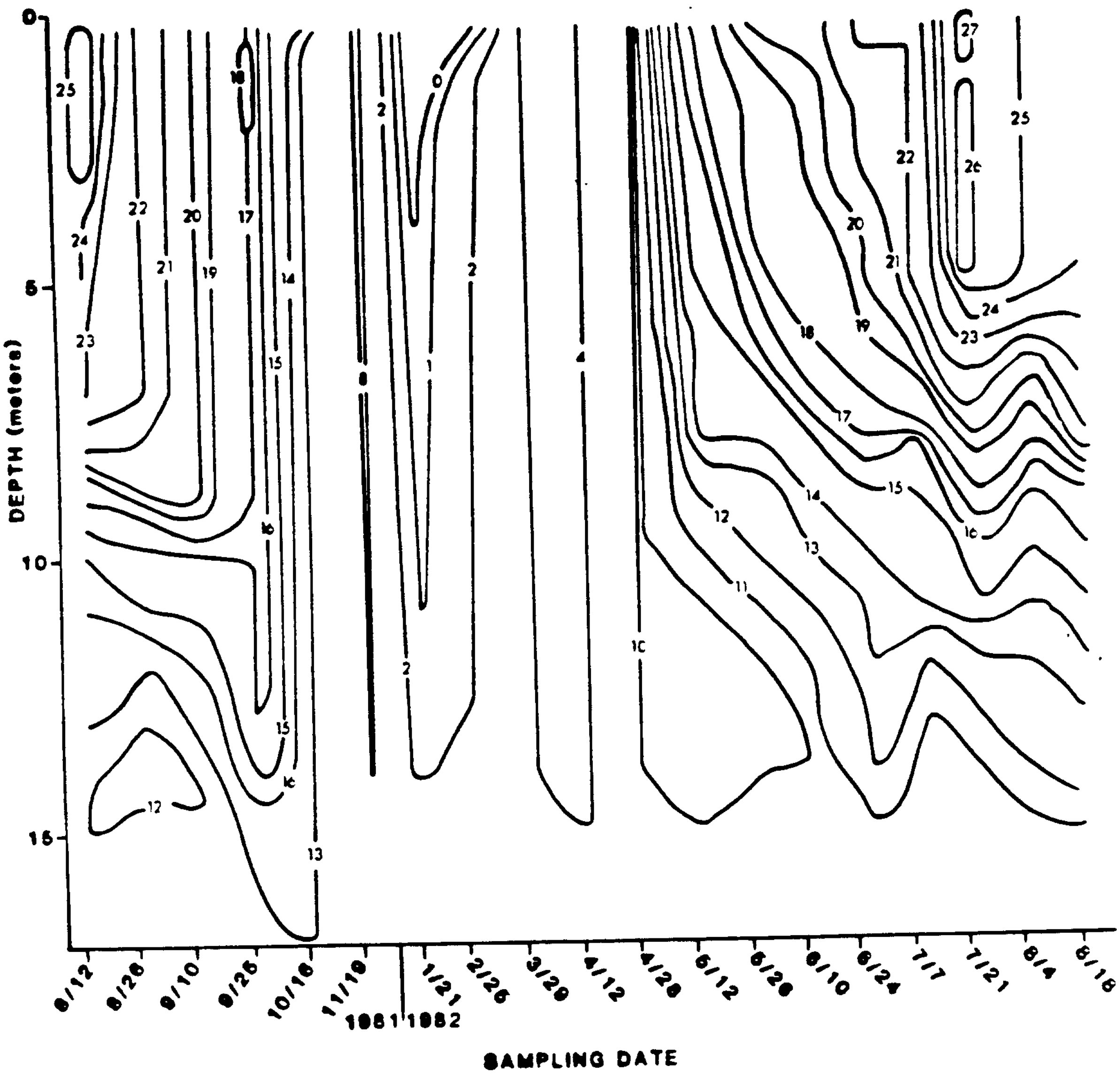


FIGURE 7
THERMAL ISOPLETHS FOR LAKE HOPATCONG

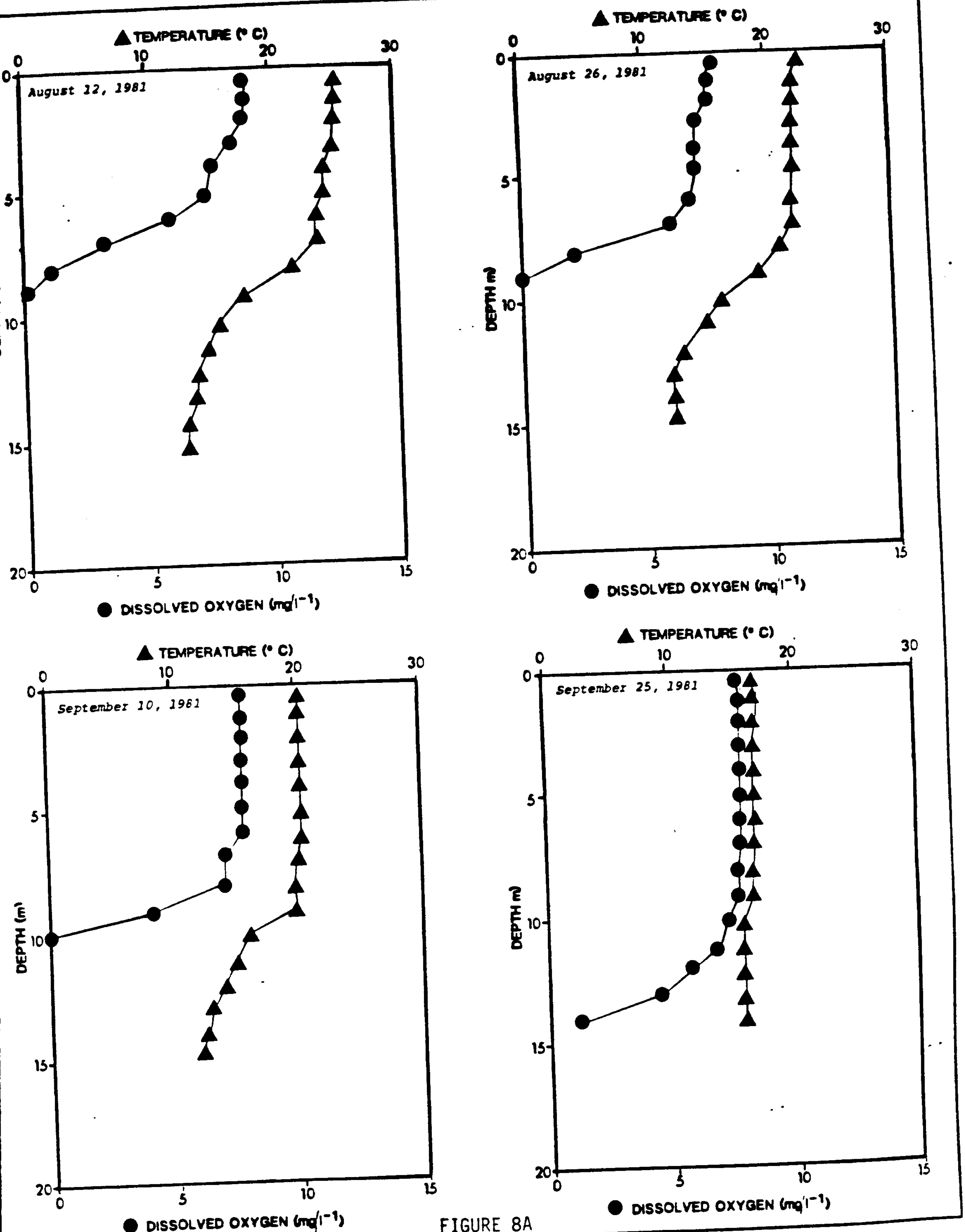


FIGURE 8A

DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR LAKE HOPATCONG, SUMMER 1981

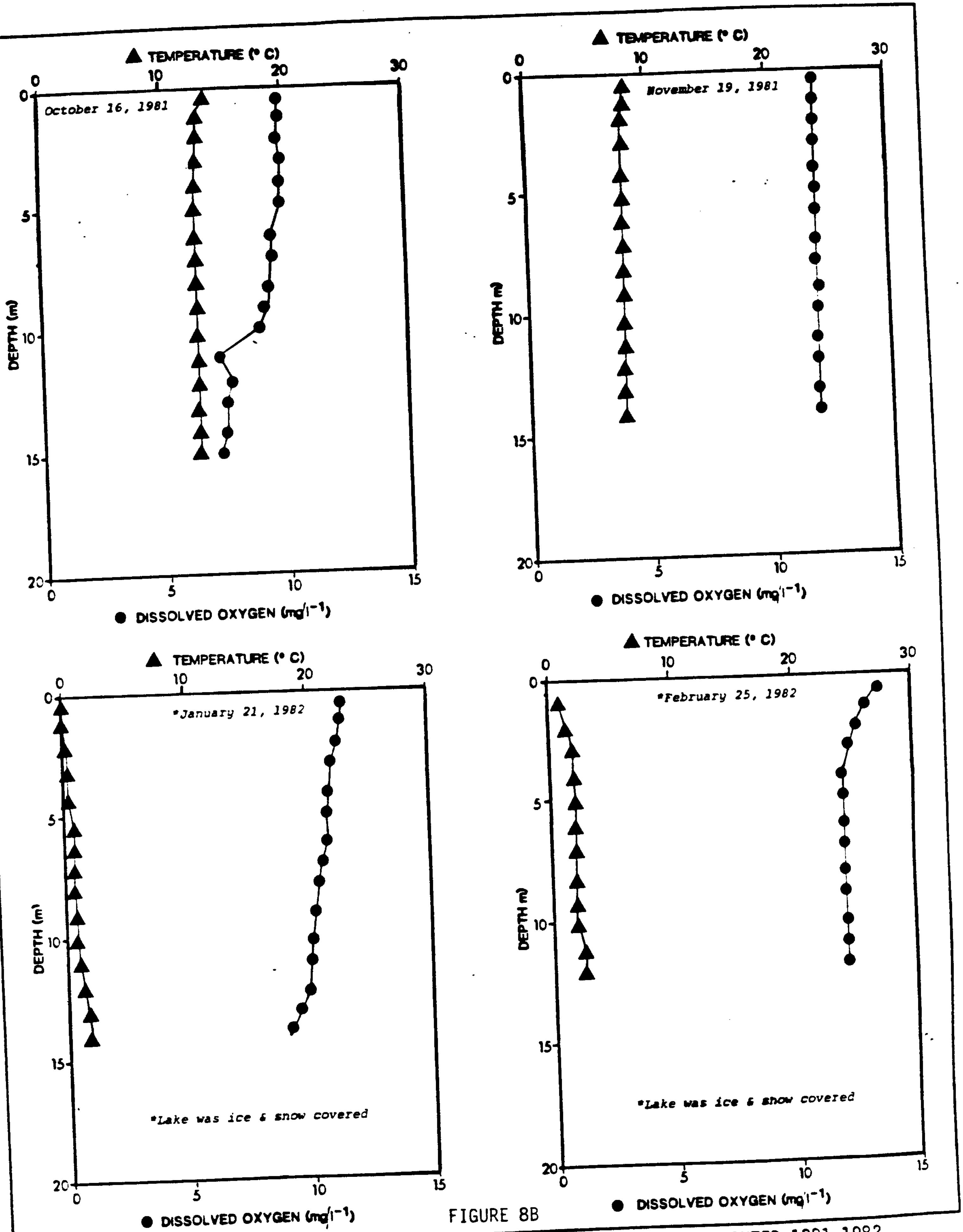


FIGURE 8B

DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR LAKE HOPATCONG, FALL-WINTER 1981-1982

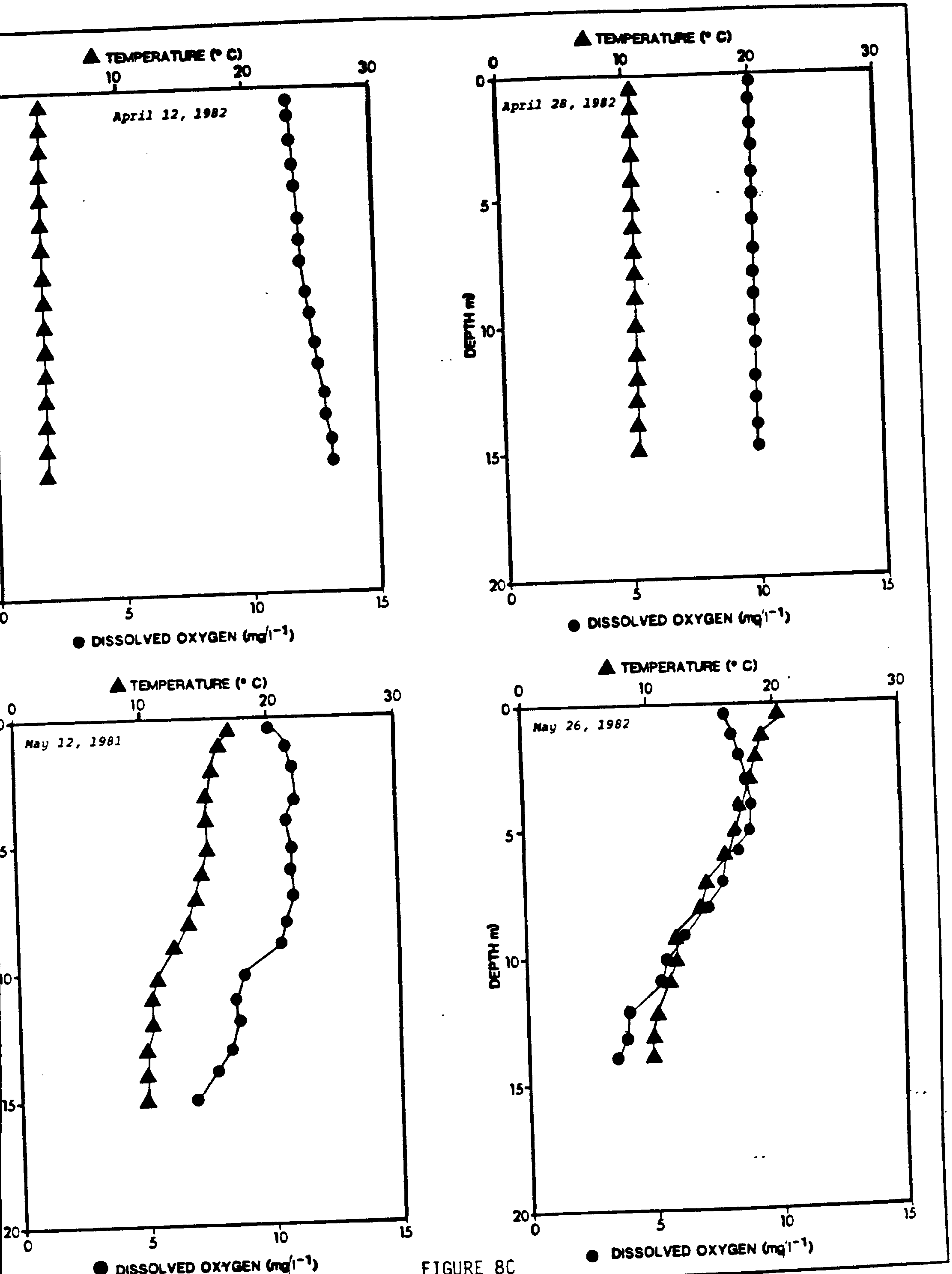


FIGURE 8C

DISSOLVED OXYGEN-TEMPERATURE PROFILE FOR LAKE HOPATCONG, SPRING 1982

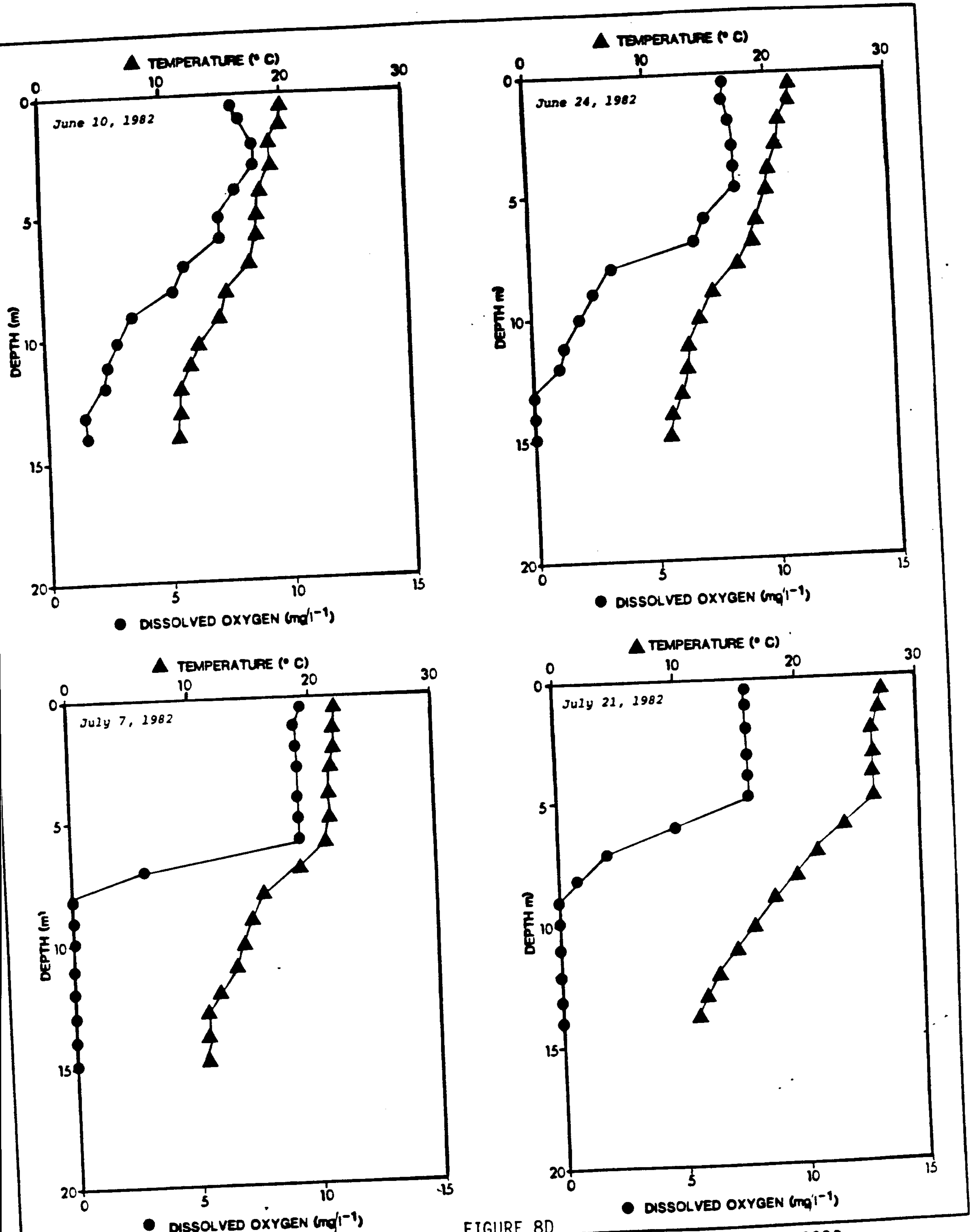
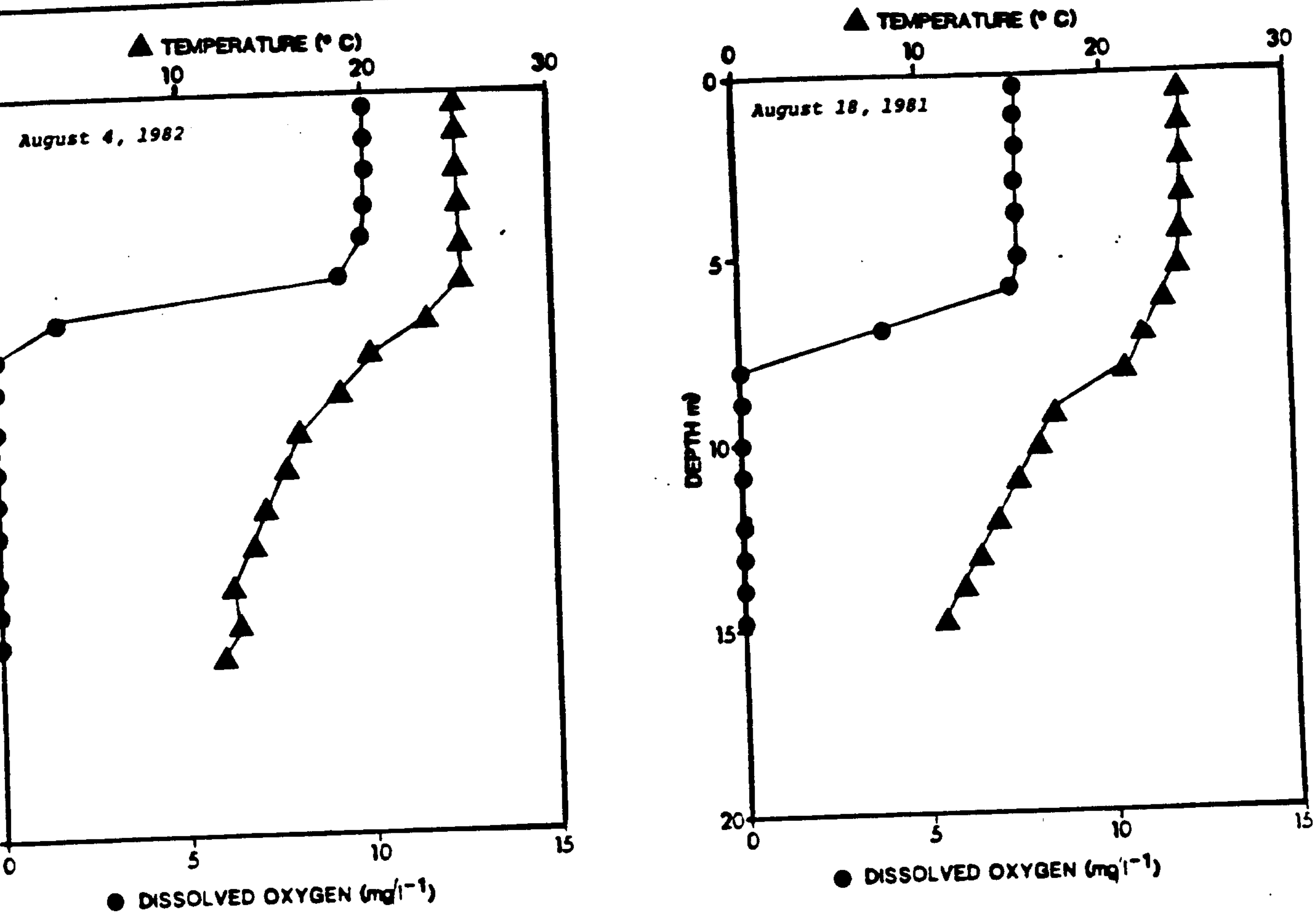


FIGURE 8D

DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR LAKE HOPATCONG, SUMMER 1982



continued FIGURE 8D

DISSOLVED OXYGEN-TEMPERATURE PROFILES FOR LAKE HOPATCONG, SUMMER 1982

respiration, associated with the decomposition of allochthonous and autochthonous material, is responsible for the depletion of dissolved oxygen in the profundal zone of the lake.

This condition exerts two major impacts on the environmental inter-relationships of the lake. First, the depletion of D.O. in the cool deep sections of the lake results in the loss of valuable fish habitat, particularly for cold water species such as trout. Approximately 9 x 10^6 m^3 of lake's volume, which could serve as excellent fish habitat, are lost due to unacceptable D.O. concentrations. Second, as the D.O. approaches zero, physical-chemical properties of the lake's sediments change. Specifically, the REDOX potential, the proportion of free electrons and protons, is altered. This results in the liberation of phosphorus, normally complexed with iron and aluminum ions, from the sediments into the overlying water column. When the lake undergoes overturn in the fall, much of the sediment liberated phosphorus is mixed into the euphotic layer where it is utilized by the algae. Consequently, an autumnal algae bloom is observed. In addition, as will be discussed in following sections, short-term, storm-related mixing can also result in some volumetric exchange between the epilimnion and hypolimnion, even during stratification. This is particularly true if the hypolimnion approaches anoxia at depths just below the thermocline (Figures 9 and 10). The nutrients transported into the euphotic zone following such short-term mixing events may lead to the development of summer algae blooms (Kortmann, et al., 1982).

4. pH, Alkalinity and Hardness

The pH of Lake Hopatcong is essentially neutral. Annual mean pH values for the lake, as recorded at the various stations range from 6.83 to 7.05 (Table 32). The average pH at LH 1, LH 2, and LH 6 at all depths, is slightly acidic, while the average pH at LH 3, LH 4, and LH 5 is

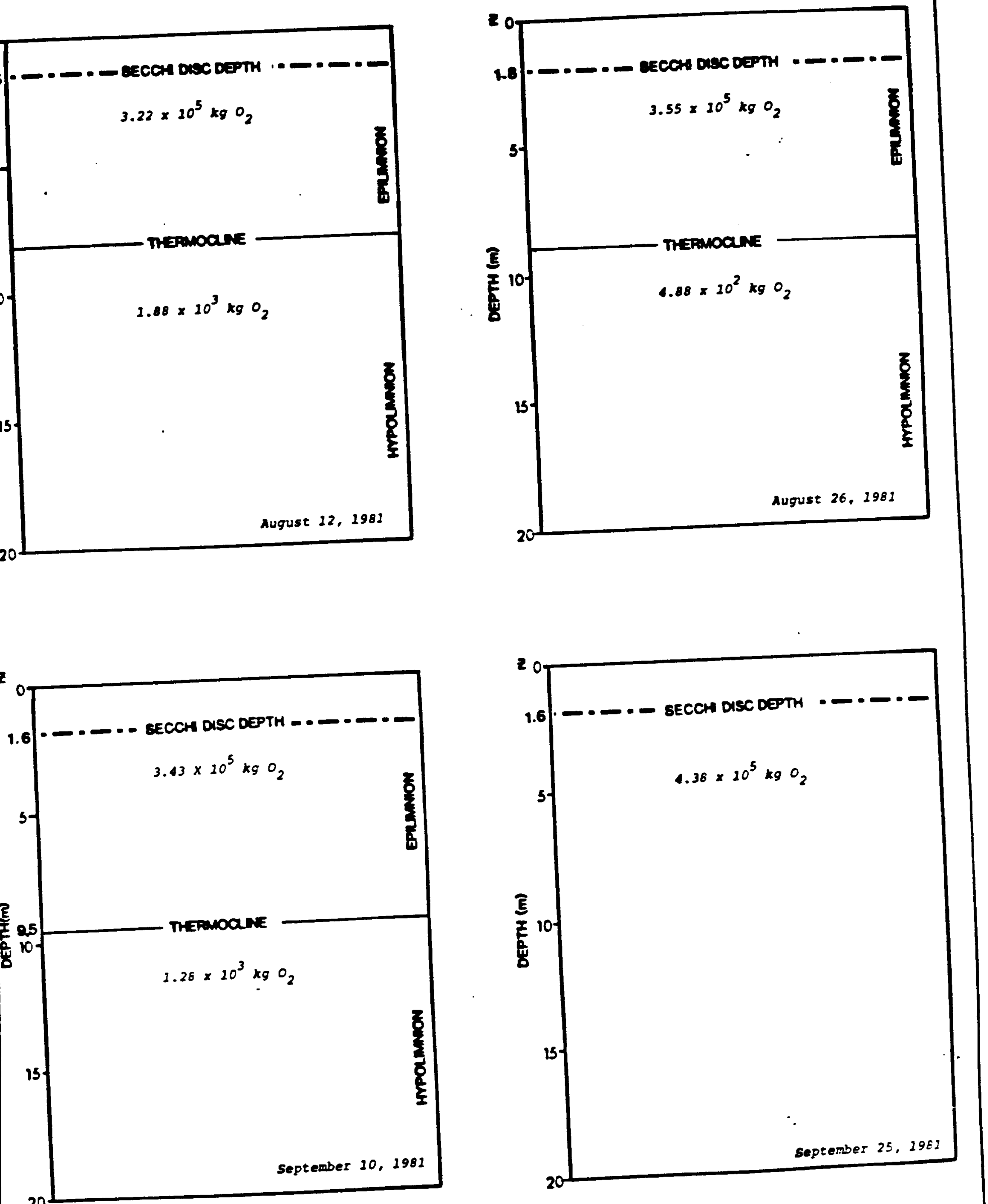


FIGURE 9A

CHANGES IN THE OXYGEN CONTENT OF THE EPILIMNION AND HYPOLIMNION OF LAKE HOPATCONG, SUMMER 1981

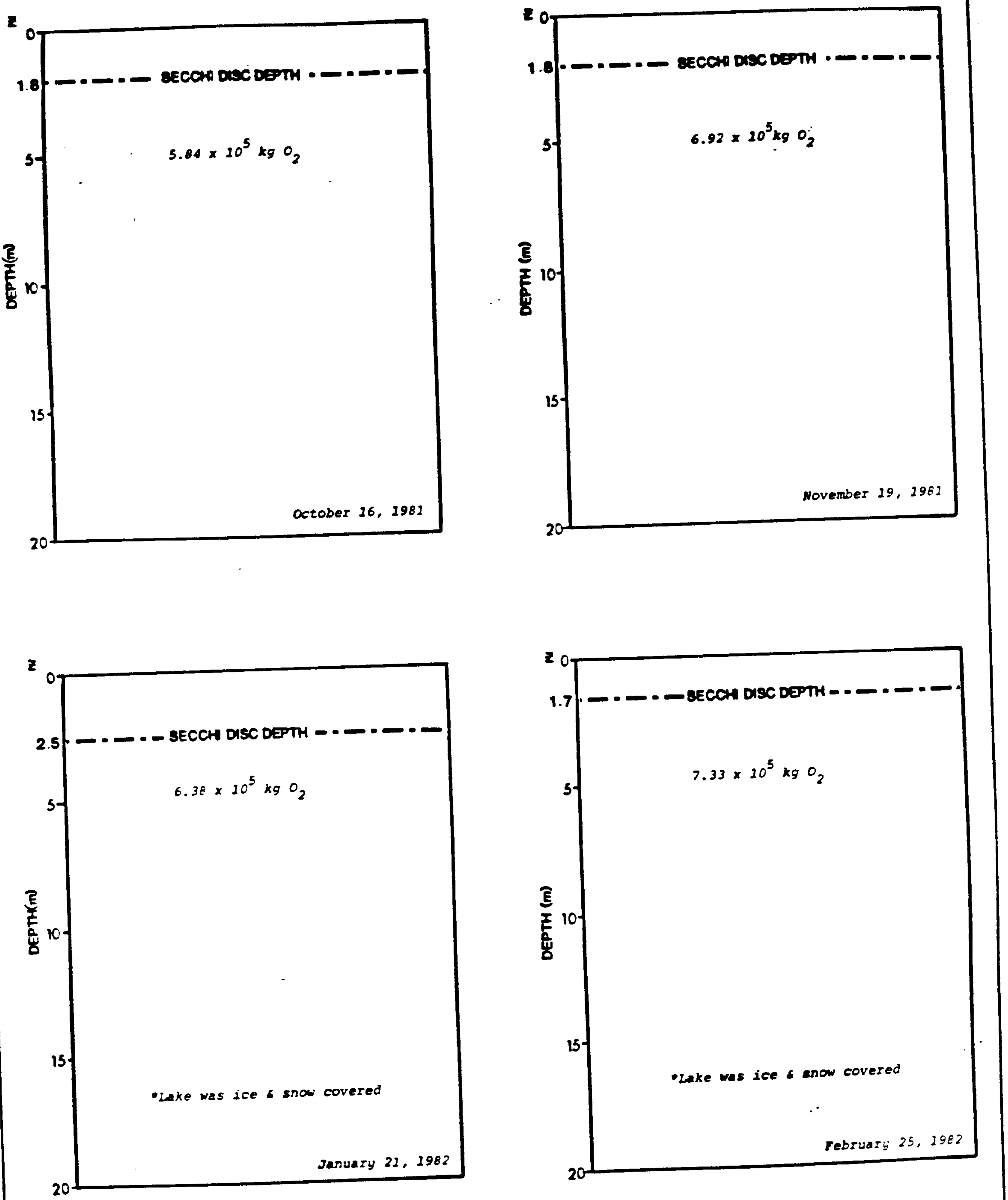


FIGURE 9B

CHANGES IN THE OXYGEN CONTENT OF THE EPILIMNION AND HYPOLIMNION OF LAKE HOPATCONG, FALL-WINTER 1981-1982

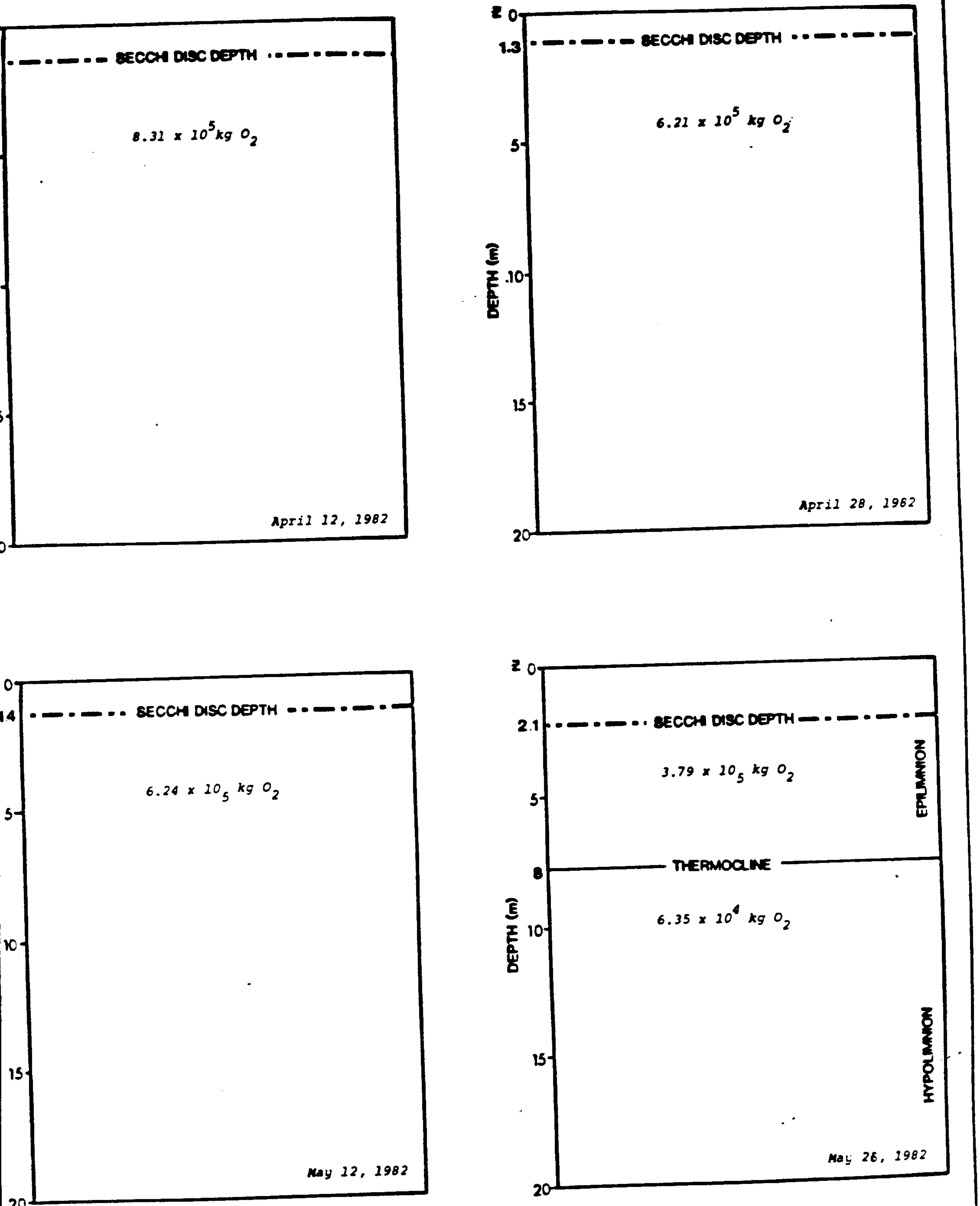


FIGURE 9C

CHANGES IN THE OXYGEN CONTENT OF THE EPILIMNION AND HYPOLIMNION OF LAKE HOPATCONG, SPRING 1982

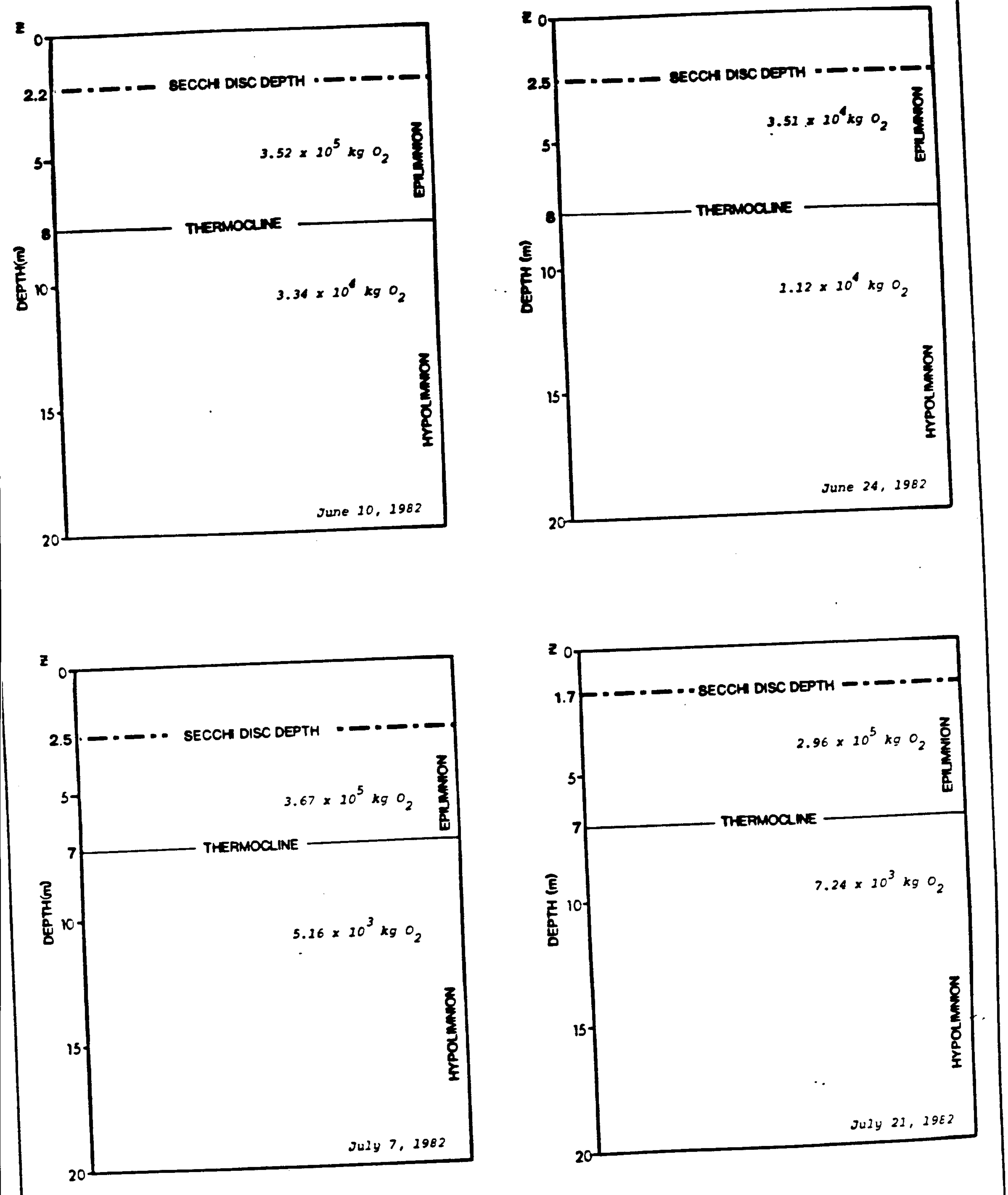
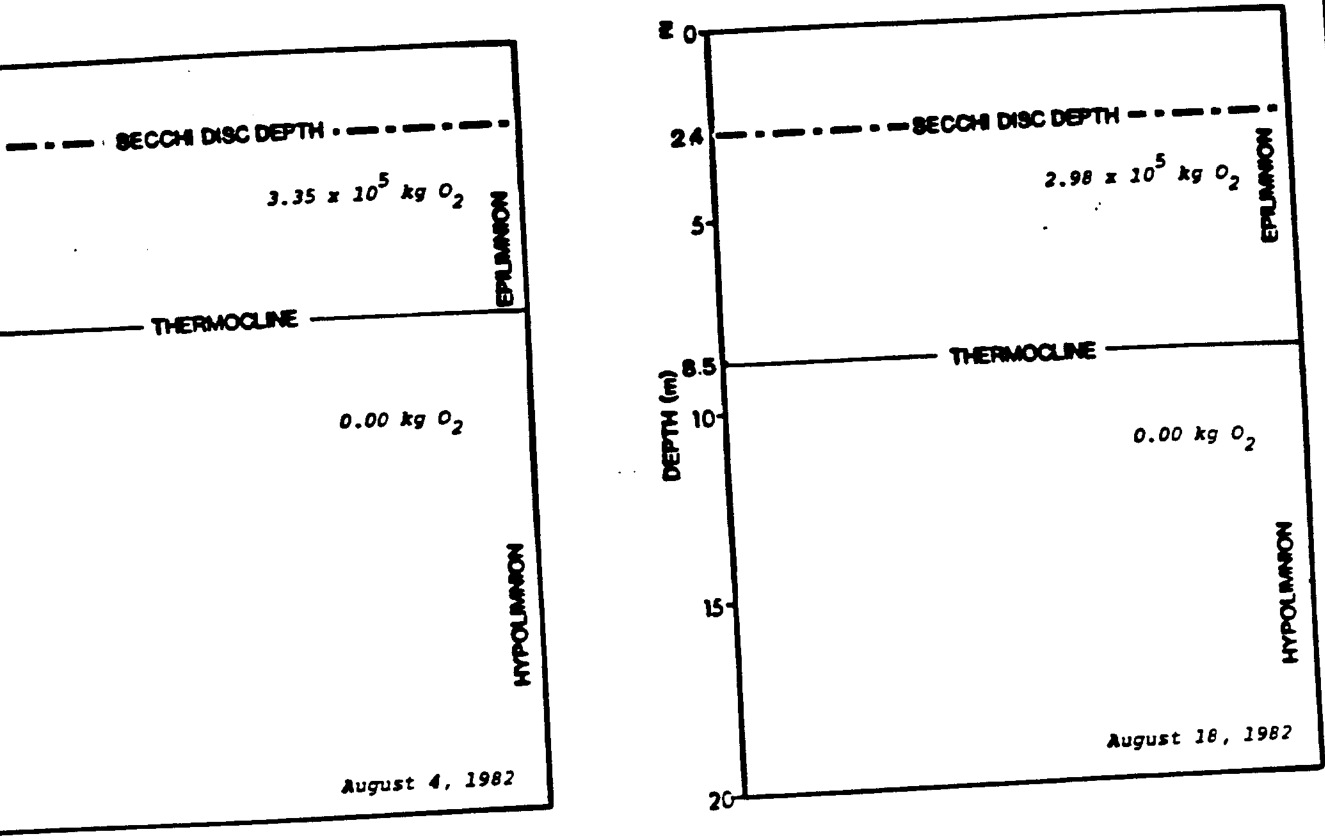


FIGURE 9D

CHANGES IN THE OXYGEN CONTENT OF THE EPILIMNION AND HYPOLIMNION OF LAKE HOPATCONG, SUMMER 1982



continued FIGURE 9D

CHANGES IN THE OXYGEN CONTENT OF THE EPILIMNION AND HYPOLIMNION OF LAKE HOPATCONG, SUMMER 1982

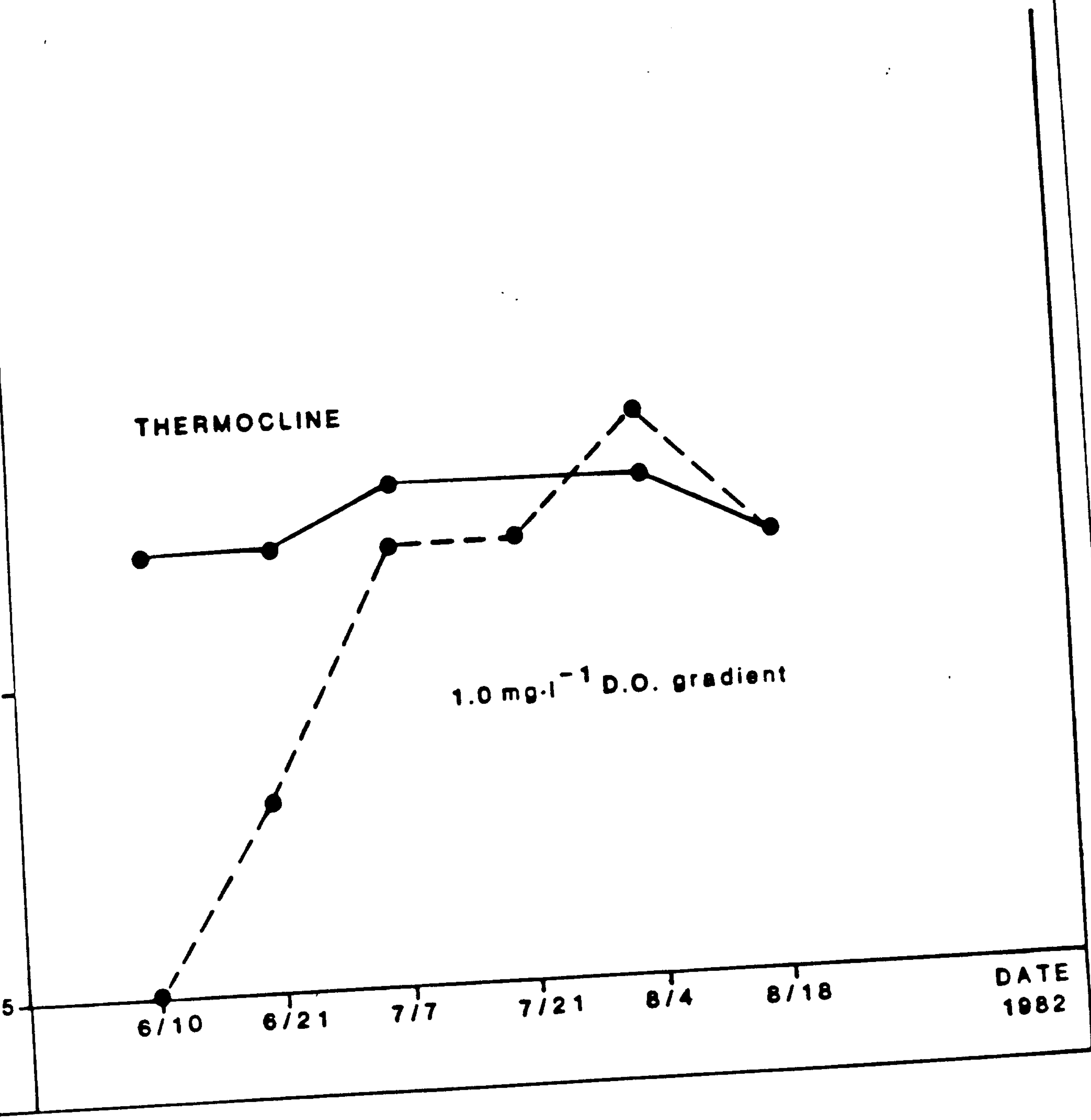


FIGURE 10
Depth of 1.0 mg.l-1 D.O. Gradient as Related to the position of the Thermocline during the summer of 1982

Table 32

MEAN CONCENTRATION OF IMPORTANT
PHYSICAL-CHEMICAL PARAMETERS OF LAKE HOPATCONG

			Concentration in mg l^{-1}					(NTU)	(μmho)
Station No.	*Depth (m)	(spu) pH	Alkalinity as ($CaCO_3$)	Total Hardness as ($CaCO_3$)	Dissolved Silica	Chloride	Total Suspended Solids	Turbidity	Specific Conductance
LH 1	0.5	6.84	27.7	59.0	1.50	33.2	9.70	24.4	138
	1.5	6.83	26.1	57.9	1.61	32.8	9.61	20.8	135
LH 2	0.5	6.89	26.2	53.0	2.27	37.9	4.65	9.74	133
	3.0	6.85	24.3	52.0	2.12	39.4	5.52	10.4	137
	6.0	6.86	24.6	52.2	2.43	38.1	4.38	7.12	135
	9.0	6.87	26.5	53.3	3.15	39.5	7.38	13.9	133
	12.0	6.87	26.8	53.0	4.07	38.9	11.0	20.2	135
	14.0	6.90	28.6	53.1	5.06	37.6	9.38	28.5	137
LH 3	0.5	7.03	28.4	53.9	2.07	39.1	5.77	9.34	136
	2.5	7.00	26.5	52.8	2.09	38.5	7.91	10.9	138
LH 4	0.5	7.06	27.0	54.7	2.16	38.5	6.52	12.1	136
LH 5	1.0	7.05	26.2	56.9	2.09	43.4	5.76	7.84	150
LH 6	0.5	6.92	24.0	51.5	2.39	39.1	8.01	11.9	135
	11.0	6.89	27.9	52.9	4.35	40.8	10.9	18.6	133

*Sampling depths were slightly variable with the majority of the samples collected at the specified depths.

slightly alkaline. The former three stations are in the northern end of the lake, whereas the latter three are in the southern end of the lake. In addition, the pH, as measured at LH 1, LH 3, LH 4, and LH 5, display greater temporal variability than do the remaining in-lake stations. Photosynthetic induced pH shifts, related to the productivity of aquatic macrophytes is probably responsible for the observed variability (Halstead and Tash, 1982).

Lake Hopatcong has a low to moderate buffering capacity, as indicated by alkalinity concentrations which range from approximately 24 to 29 mg l^{-1} $CaCO_3$ (Table 32). The lake is also of moderate hardness, 52 to 59 mg l^{-1} $CaCO_3$. Total hardness measurements (as $CaCO_3$) are fairly consistent throughout the lake both on a temporal and spatial basis. However, alkalinity values display substantial variability (6 to 35 mg l^{-1} $CaCO_3$), particularly in the summer. The most pronounced variability is observed at stations LH 1, LH 3, LH 4, and LH 5, and is caused by photosynthetically induced shifts in the carbonate equilibria of the lake.

5. Specific Conductance

The mean specific condunctance of the lake ranges from about 133 to 150 mho) (Table 32). Specific conductance, a measurement of salinity expressed as the reciprocal of resistence to electrical flow, is proportionately related to the dissolved ion content of the water. The greater the ion content, due to carbonates, chlorides, sodium, magnesium, etc., the higher the specific conductance. In Lake Hopatcong, the concentration of ionic material is typical for moderately soft water, open drainage lakes.

6. Suspended Solids and Turbidity Effects on Lake Transparency

The concentration of total suspended solids displays both temporal and spatial variability. Mixing events and storm contributions appear responsible for the observed variability and abrupt and localized changes in TSS concentrations commonly measured.

Turbidity values typically reach maximum levels in August at all surface water stations. Peak turbidity values coincide with summer algae blooms, and are probably the result of increased algal cell densities. A similar phenomenon is observed at LH 2 at depths greater than 9.0 m, and at LH 6 at 13.5 m. In these cases, the increased turbidity observed during the summer appears related to the sinking of senescent algal cells. The hypolimnetic water, because of its cooler temperature, is of greater density. As the scenescent cells pass into the denser layers of the lake, their settling velocity decreases, the cells accumulate, and turbidity bands are formed.

7. Nutrients

The concentrations of nitrate (NO^3-N), ammonia (NH_3-N), and total kjeldahl nitrogen (TKN) follow a seasonal pattern typical for eutrophic waterbodies (Table 33).

Nitrate concentrations, as measured at the lake surface, typically decrease from spring to summer but increase in the fall at all stations. The summer decrease is attributed to uptake and utilization of nutrients by phytoplankton cells. Although the data is somewhat variable, examination of nitrate concentrations as related to lake depth as measured at LH 2, the deepest spot in the lake, reveal some fairly

Table 33

MEAN SEASONAL CONCENTRATION OF NITRATE, AMMONIA, AND TOTAL KJELDAHL NITROGEN

Station No.	*Depth (m)	Mean Concentration mg l^{-1}								
		Spring (April-June)			Summer (July-Sept)			Fall-Winter (Oct-March)		
		NO_3-N	NH_3-N	TKN	NO_3-N	NH_3-N	TKN	NO_3-N	NH_3-N	TKN
LH 1	0.5	0.124	0.120	0.232	0.085	0.096	0.234	0.296	0.062	0.230
	1.0	0.118	0.294	0.430	0.038	0.107	0.236	0.046	0.028	0.698
LH 2	0.5	0.088	0.177	0.397	0.026	0.082	0.284	0.136	0.084	0.387
	3.0	0.078	0.123	0.258	0.142	0.081	0.149	0.124	0.063	0.196
	6.0	0.098	0.196	0.361	0.081	0.075	0.169	0.121	0.134	0.264
	9.0	0.135	0.191	0.316	0.072	0.177	0.223	0.105	0.091	0.245
	12.0	0.091	0.219	0.361	0.064	0.328	0.498	0.126	0.084	0.202
	14.0	0.098	0.269	0.469	0.174	0.600	0.728	0.173	0.065	0.364
LH 3	0.5	0.108	0.115	0.332	0.054	0.073	0.279	0.112	0.050	0.222
	2.5	0.114	0.090	0.219	0.064	0.060	0.149	0.162	0.049	0.196
LH 4	0.5	0.120	0.273	0.474	0.043	0.116	0.222	0.105	0.056	0.212
LH 5	1.0	0.181	0.311	0.436	0.074	0.075	0.206	0.201	0.113	0.182
LH 6	0.5	0.082	0.216	0.370	0.097	0.060	0.134	0.184	0.106	0.190
	11.0	0.090	0.334	0.428	0.327	0.234	0.302	0.097	0.106	0.185

* Sampling depths were slightly variable with the majority of samples collected at the specified depths.

interesting information (Figure 11). From the time of spring overturn until the lake stratifies there is a continual increase in nitrate in the profundal zone of the lake. This is attributable to the decomposition of detritus and the liberation of nitrogen compounds. After stratification, nitrate concentrations decrease. This occurs because as the hypolimnion becomes devoid of oxygen, NO_3-N is utilized as an alternate electron donor, in the place of oxygen. This process, termed denitrification, involves the bacterial assimilation and conversion of nitrate to nitrogen. Upon destratification and fall turnover, NO_3-N concentrations increase once again in the deeper layers.

The concentration of ammonia at the surface is consistently greatest in the spring at all stations, and typically decreases through the summer and fall (Table 33). At the deep water station, LH 2, summer concentrations of NH_3-N increase during the summer at depths greater than 12.0 m. Increased ammonia concentrations are associated with thermal stratification, oxygen depletion, and changes in the REDOX potential of the sediments. Ammonia is produced through the bacterial decomposition of organic deposits and liberated into the overlying waters thereby enriching the hypolimnetic waters.

Total kjeldahl nitrogen concentrations at the surface of the lake tend to decrease from spring to summer but increase in the fall at most lake stations. In general, the concentration of TKN is greatest during the summer at lake depths greater than 12.0 m.

The concentration of orthophosphate (PO_4-P) is fairly consistent at the surface for all stations from spring through summer (Table 34). During the fall-winter period a slight decrease in PO_4-P is observed. In the spring and fall-winter periods, the PO_4-depth profile reveals fairly consistent concentrations from surface to bottom as measured at LH 2.

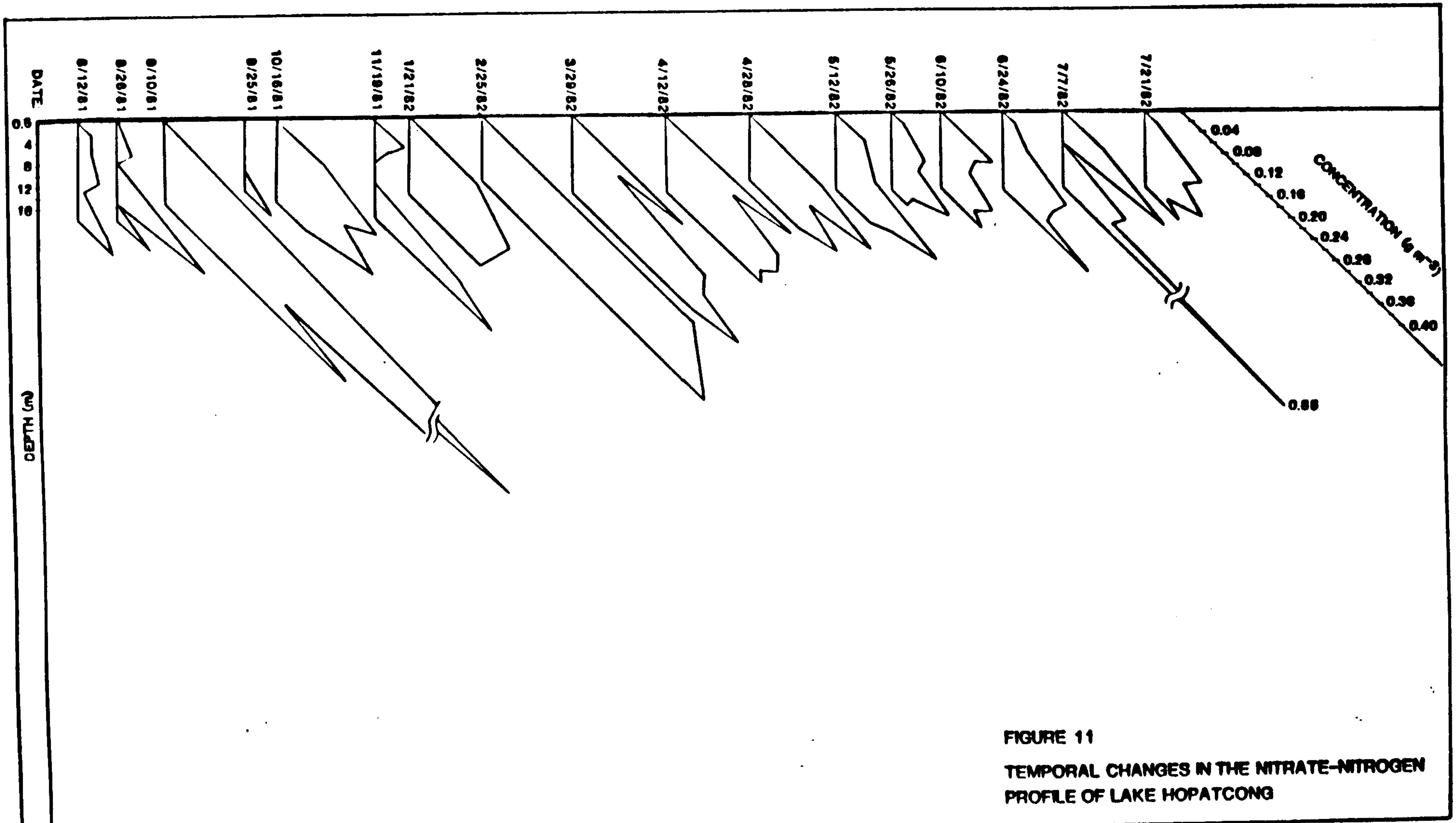


FIGURE 11

TEMPORAL CHANGES IN THE NITRATE-NITROGEN PROFILE OF LAKE HOPATCONG

Table 34

MEAN SEASONAL CONCENTRATION OF ORTHOPHOSPHATE AND TOTAL PHOSPHORUS

Station No.	*Depth (m)	Mean Concentration mg l^{-1}					
		Spring (April-June)		Summer (July-Sept)		Fall-Winter (Oct-March)	
		PO_4-P	TP-P	PO_4-P	TP-P	PO_4-P	TP-P
LH 1	0.5	0.018	0.035	0.017	0.071	0.008	0.019
	1.5	0.020	0.024	0.016	0.098	0.007	0.028
LH 2	0.5	0.009	0.023	0.012	0.036	0.008	0.023
	3.0	0.013	0.022	0.009	0.042	0.008	0.019
	6.0	0.009	0.017	0.008	0.058	0.007	0.032
	9.0	0.009	0.026	0.009	0.049	0.008	0.029
	12.0	0.010	0.021	0.024	0.110	0.006	0.026
	14.0	0.013	0.020	0.053	0.181	0.007	0.016
LH 3	0.5	0.013	0.017	0.011	0.069	0.008	0.020
	2.5	0.011	0.021	0.011	0.046	<0.007	0.046
LH 4	0.5	0.013	0.017	0.010	0.084	0.008	0.026
LH 5	1.0	0.016	0.028	0.010	0.089	0.008	0.064
LH 6	0.5	0.012	0.031	0.011	0.039	0.009	0.026
	11.0	0.008	0.111	0.022	0.141	0.010	0.039

* Sampling depths were slightly variable with the majority of samples collected at specified depths.

In the summer, however, a noticeable increase in PO_4-P occurs at depths greater than 9.0 m. This increase is attributed to the liberation of PO_4-P from the sediments following the depletion of oxygen in the hypolimnetic zone of the lake.

Total phosphorus (TP) concentrations increase slightly from spring to summer, but decrease from summer to fall-winter period at all surface water sampling sites (Table 34). A net accumulation of TP occurs in the hypolimnion during the summer following stratification (Table 34, Figure 12). TP liberation is attributed to changes in the sediment REDOX potential resulting from oxygen depletion in the profundal, tropholytic zone of the lake. The mean TP concentrations at 12 and 14 m in the spring are 0.010 and 0.013 g m^{-3} respectively. In the summer, the mean concentrations at these same depths increase to 0.110 and 0.181 g m^{-3} respectively, an increase of approximately 10 fold. Thus, a substantial amount of TP is being liberated from the sediments. In the fall, immediately following the autumnal overturn, much of this TP is circulated into the euphotic zone where it can be utilized by primary producers. This often leads to a fall algae bloom.

There are numerous studies which document the complex limnological inter-relationship of hypolimnetic oxygen depletion, sedimentary regeneration of dissolved phosphorus, and subsequent stimulation of algal productivity. The amount of TP liberated from the sediments can contribute significantly to the total phosphorus budget of a eutrophic waterbody, and may, in itself, be sufficient to stimulate excessive productivity (Freedman and Cassale, 1977; Welch and Rock, 1980). More than half of the total phosphorus budget of a lake can originate from internal phosphorus loading (Larsen, et. al., 1981). Typically, the liberation of phosphorus from the sediments during summer stratification is 15-25% of the annual TP load of a eutrophic waterbody. The potential TP load associated with sediment release can be calculated using various loading coefficients (Nurnberg, in press; Kortmann, et. al., 1982; USEPA, 1980). A conservative approach was used in selecting that

FIGURE 12

TEMPORAL CHANGES IN THE TOTAL PHOSPHORUS (TP) PROFILE OF LAKE HOPATCONG loading coefficient which best estimated the sediment release rate of TP in Lake Hopatcong. A loading coefficient of 6 mg m^{-2} day^{-1} was selected based on morphometry, hydrology, sediment TP concentrations, and the general water quality of the lake (Nurnberg, in press). The temperature-dissolved oxygen profiles indicate that from 9 m to the bottom, the hypolimnion remains anoxic for approximately 60 days (Figure 8). During this period of time, the area of the lake overlaid by anoxic water totals m^2. Utilizing the loading coefficient of 6 mg m^{-2} day^{-1} in conjunction with this data yields an internal TP load of kg yr^{-1}. This load represents the amount of phosphorus annually liberated from the sediments. Since the destratification of the lake proceeds over a very short period of time (Figure 8), the majority of the internal TP load is probably circulated into the trophogenic zone. In addition, the depth of the anoxic boundary relative to the thermocline is such that storm events can "erode" the hypolimnetic layer (Figure 10). The significance of this phenomena is that storm events can potentially mix phosphorus rich hypolimnetic water into the trophogenic zone, and stimulate algal blooms (Kortmann, et. al., 1982).